National University of Singapore

CENTRE FOR INTELLIGENT CONTROL

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In-Situ Measurement and Control in the Microlithography Process

1. MOTIVATION

In this project, three key parameters i.e. wafer warpage, photoresist thickness and processing temperature known to impact Critical Dimension (CD) uniformity in the Microlithography process were investigated. Through modeling and real-time identification, we developed new in-situ measurement techniques for these parameters in the manufacturing process. Real-time prediction and control of the parameters were performed to compensate for CD non-uniformity.

2. EXPERIMENTAL RESULTS

2.1 WAFER WARPAGE AND CD CONTROL

Wafer warpage is common and affect CD. When a wafer at room temperature is placed on the bakeplate, the temperature of a bakeplate dropped at first but recovered gradually because of closed-loop control (see Fig. 1). Notice that a flat and warped wafer caused different maximum magnitudes of temperature drops hence warpage can be detected as shown in Fig. 2 and thermal compensation can be performed as shown in Fig. 1 at t = 20s. Six wafer runs are shown in Fig. 3 for 2 flat wafers and 4 warped wafers. Thermal compensation performed for Wafers 5 and 6 resulted in CD equal to CD of the flat Wafers 1 and 2.

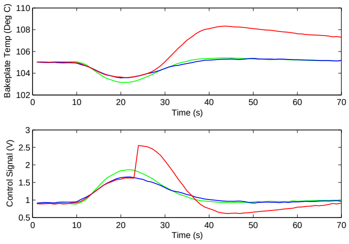

Fig. 1. Post-exposure bake temperature and control signal. Green: flat wafer; Blue: warped wafer; Red: warped wafer with temperature compensation.

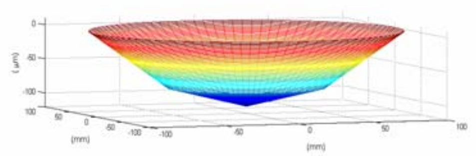

Fig. 2. Warpage of a 8 in wafer estimated from temperature measurements.

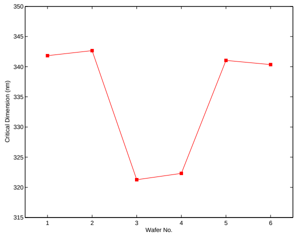

Fig. 3. Critical Dimension Distribution. Wafer 1, 2: flat; Wafers 3, 4: warped and hence the deviation in CD; Wafers 5, 6: warped but thermal compensation performed for Wafers 5 and 6 resulted in CD that are equal to the CD of Wafers 1 and 2.

2.2 CD CONTROL VIA REAL-TIME PHOTORESIST THICKNESS CONTROL

CD is significantly impacted by photoresist thickness. Fig. 4 shows the temperature and photoresist thickness profile of 2 points on a 4 in wafer, 1.5 in apart, one near the center, the other near the edge. Note that at the beginning of the softbake process, the photoresist thickness were different but converged to the desired thickness at the end because of in-situ monitoring of photoresist thickness and control. In Fig. 5, photoresist thickness uniformity control during softbake was performed for Wafers 1 to 4 and thickness and CD deviations within-wafer were about 1 nm and 2 nm respectively. Photoresist thickness uniformity control were not performed for Wafers 5 to 8 and the deviations were much larger. Fig. 6 shows that for wafers 1 to 4, the photoresist thickness were controlled during softbake and photoresist thickness deviation and CD deviations of 1 nm and 2 nm respectively were obtained wafer-to-wafer. In contrast, photoresist thickness were not controlled during softbake for Wafers 5 to 9 and larger deviations were obtained.

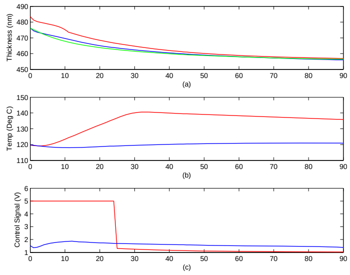

Fig. 4. Wafer 1 photoresist thickness and temperature during Softbake for within-wafer CD control. Red: near center of wafer; Blue: near edge of wafer; Green: desired photoresist thickness.

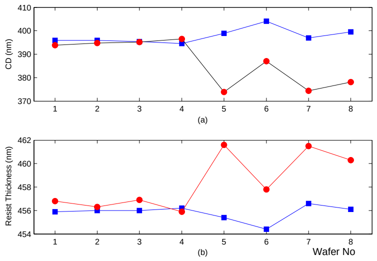

Fig. 5. Within-Wafer photoresist thickness and CD. Red: near center of wafer; Blue: near edge of wafer.

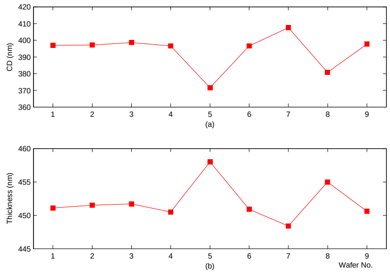

Fig. 6. Wafer-to-Wafer photoresist thickness and CD

2.3 REAL-TIME EXTINCTION COEFFICIENT CONTROL

Fig. 7 shows extinction coefficient of 2 points on a 4 in wafer being monitored and control by manipulating process temperature to give uniformity. Fig. 8 shows the improvement in the Extinction Coefficient uniformity for Wafers 4 to 9. No control was performed for Wafers 1 to 3.

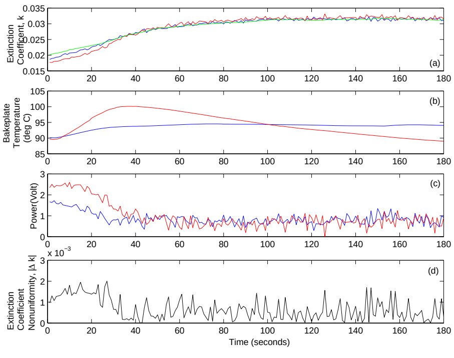

Fig. 7. Blue: center zone of wafer; Red: edge zone of the wafer; Green: reference extinction coefficient trajectory; Black: difference between Blue and Red in (a)

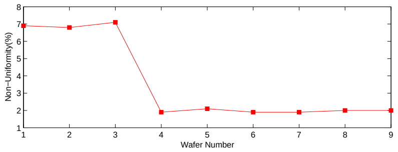

Fig. 8. Extinction coefficient non-uniformity. Real-time control of extinction coefficient was implemented for Wafers 4 to 9 but not for Wafers 1 to 3.

2.4 REAL-TIME TEMPERATURE CONTROL

Fig. 9 shows that multi-variable feed-forward temperature control eliminate the temperature fluctuations during the baking process.

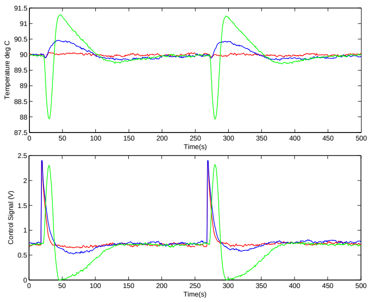

Fig. 9. Comparison of temperature fluctuation caused by the placement of a cold wafer on a multi-zone bake-plate. Red: multivariable feed-forward control; Blue: single-input-single-output feed-forward control; Green: proportional-integral feedback control only.

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